Experimental Analysis on Mitigation of Alkali-Silica Reaction by using Different types of Portland Cement

Ravi Agarwal, Nisheeth Agnihotri, U S Vidyarthi

Abstract— **In hydraulic cement concrete, most aggregates are chemically stable and do not interact negatively with other concrete constituent materials. This is not the case, however, with aggregates containing siliceous minerals that react with soluble alkalies in concrete. The alkali silica reaction, in which silica interacts with alkalis to generate a gel that expands and affects the mechanical characteristics of concrete, has the potential to be exceedingly disruptive. Alkali silica reaction is slowed by dilution of alkalis by increasing silica content with Portland Pozzolana Cement or Portland Slag Cement or mineral additives like fly ash, Micro Silica, Metakaolin, etc. The goal of this research is to see how Ordinary Portland Cement (OPC), Portland Pozzolana Cement (PPC), and Portland Slag Cement (PSC) affects ASR.**

***Index Terms*—Accelerated Mortar Bar, Alkali-Aggregate Reactions, ordinary Portland Cement; Portland Pozzolana Cement, Portland Slag Cement, Gel, Expansion *Index Terms*—first term, second term, third term, fourth term, fifth term, sixth term**

I. INTRODUCTION

Since 1940, when Alkali Aggregate Reactions (AAR) was first discovered and characterized in concrete, the phenomenon has sparked a lot of interest and been recognized as a developing problem in many parts of the world. The alkali silica reaction (ASR) in concrete has the potential to be quite disruptive. As it takes water from the surrounding cement paste, the ASR produces a gel that swells (has great affinity to moisture). These gels can cause pressure, expansion, and breaking of the aggregate and surrounding paste by absorbing water. In concrete, the presence of pore fluid, alkalis, and ASR reactive aggregate will start the deteriorating process. It has been discovered that reactivity is greatest when the reactive aggregate concentration is at its lowest. ASR relies heavily on the ratio of reactive alkalis to reactive silica surface area. The rate of ASR is slowed by dilution of alkalis by increasing silica content with Portland Pozzolana Cement (PPC), Portland Slag Cement (PSC), Silica Fume (SF), and other silica-containing cements. The goal of this research is to see how utilizing OPC, PPC, and PSC with aggregate affects ASR expansion.

In case of new aggregate source, the material is in high demand right away. It is often not acceptable to wait six to twelve months for test results. The reactivity of already-placed concrete may be called into question in various instances. To assess whether an aggregate is potentially reactive or not, a quick test is required. We used ASTM C 1260 / C1567, Standard Test Method for determining the Potential Alkali Reactivity of Aggregates (Accelerated Mortar-Bar Test) and evaluating the effectiveness of mitigation using various types of Portland cement [9].

II. REVIEW OF LITERATURE

Portland cement is the main source of the alkalis. Adding fly ash (IS 1489 Part 1, 1991) induces dilution of the alkalis which disrupts ASR. Ensuring sufficient surface area by varying the percentage (BS 3892 Part1) and type of fly ash provides an efficient method to prevent ASR. Small quantities of fine fly ash with low-reactivity aggregates and sufficient alkalis may be more susceptible to ASR, if the pessimum silica alkali ratio is approached. Even when total alkalis within the concrete are as high as 5 kg/m3, fly ash has been found effective in preventing ASR (Alasali and Malhotra, 1991). The addition of fly ash reduces the pH of the pore solution to below 13 which prevents ASR. Researchers have categorized fly ash for usage for arresting ASR (Fournier and Malhotra, 1997). It is however suggested that to restrict ASR fly ash must comply with ASTM C618 (ACI *Manual of Concrete Practice*,1994). Laboratory research [1] and field experience [2] supports that appropriate use of fly ash can prevent expansion due to ASR in concrete. Fly ash from bituminous coal sources (ASTM Class F) which is characterized by relatively low calcium contents (i.e. <10% CaO) is most effective in controlling expansion instead of those obtained from sub-bituminous or lignite coals [3–4]. The inferior performance of fly ash with calcium contents in excess of 25% may be largely ascribed to the pore solution chemistry. Such fly ash is not as effective in reducing the pore solution alkalinity of cement paste systems [5]. Greater proportion of the alkalis is available for ASR in these fly ash [6].

III. MATERIALS & METHODOLOGY

A. *Materials*

1. *Aggregates:*

Coarse aggregate samples were collected from a variety of quarries selected as part of one of the studies. These coarse aggregate samples have been converted to crushed sand samples that have been graded.

2. *Cement*

In the present study, three different types of cements viz. Ordinary Portland Cement (OPC), Portland Pozzolana Cement (PPC) and Portland Slag Cement (PSC) have been used with aggregate. Alkali Content and Water Cement Ratio of these cements are presented in Table 1.

Table 1: Alkali Content and W/C of the Cements used in the study

Type of Cement	Cement Alkalies (Na_2O) equivalent	Water Cement Ratio
OPC	0.61	0.48
PPC	0.77	0.48
PSC	0.77	0.48

B. *Test Methodology*

1. *Accelerated Mortar-Bar Test (ASTM C 1260 and ASTM C 1567):*

The accelerated mortar-bar test (AMBT) is a quick and accurate way to determine the potential reactivity of both slow and fast reactive aggregates. For the mortar-bar expansion test, aggregates are crushed to sand size. To provide a quick source of sodium and hydroxyl ions, the mortar bars are kept in a 1N NaOH solution. To speed up the ASR, the temperature is kept at 80°C. The comparator readings are taken during a 14 and 28-day period [7, 8]. The test settings are more rigorous than those found in typical field service situations.

Test Conducted

The study has been carried out using different types of cements. The details of the test and material combination used are presented in Table 3.

Table 3

Combination	Ingredient Materials
ASR/CB/1	Aggregate +OPC
ASR/CB/2	Aggregate +PPC
ASR/CB/3	Aggregate +PSC

2. *Petrographic Examination*

One of the most reliable markers of the potential for harmful ASR is a petrographic study (ASTM C 295) of aggregates. The types and quantities of minerals present in an aggregate can be determined via a petrographic examination.

Mineralogical Composition of the Aggregate used in study is presented in table 4.

Table 4

Quarry	Strained quartz (%)	Undulatory extinction angle (in degree)	Name of Rock type
QA/1	55-60	27°- 32°	quartzite
QA/2	41-45	29°-37°	quartzite
QA/3	44-49	29°-33°	quartzite
QA/4	31-35	22°-25°	quartzite
QA/5	37-42	29°-34°	quartzite
QA/6	16-21	17°-21°	quartzite

Aggregates comprising more than 20% strained quartz and an undulatory extinction angle more than 15° cause adverse response, according to IS 2386 [(Part VII): 1963]. The strained quartz percentage and the undulatory extinction angle exceed the essential limitations, according to the aggregate's mineralogical composition (Table 4). The aggregates' ASR test findings with the OPC also demonstrate that the samples are in the detrimental zone.

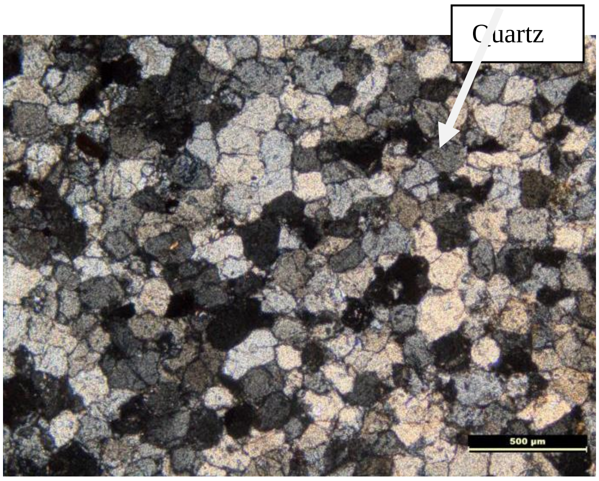

Figure. 1. Strained quartz grains in the Quartzite

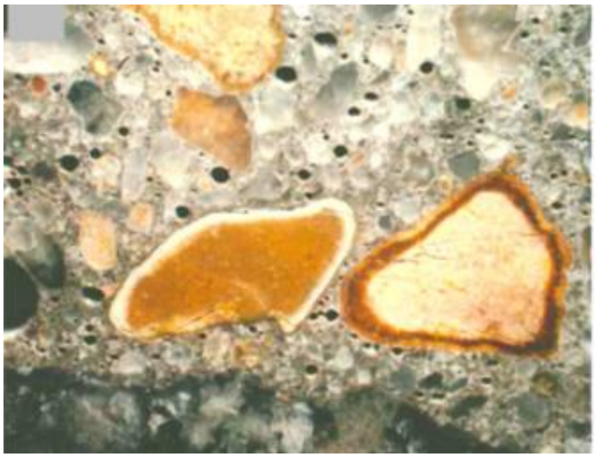

Figure 2. ASR occurrence at the surface of aggregate

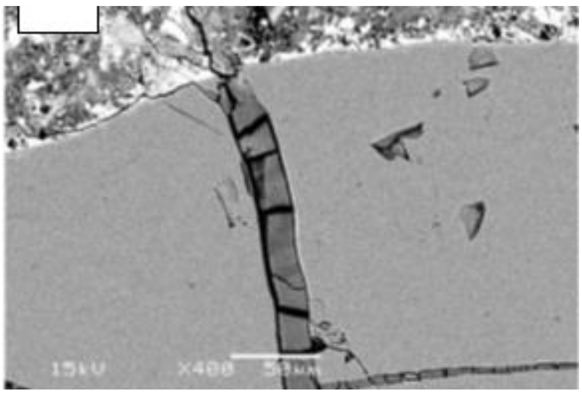

Figure 3. Iingress of Alkali Silica Gel through pre-existing microcracks

IV. RESULTS AND DISCUSSIONS

The accelerated mortar bar test method was used to determine the reactivity of aggregates with various types of cement. In figures 4 to 9, the reactivity of aggregate has been graphically represented in terms of observed expansion. The cement-aggregate mix is divided into several zones of reactivity based on 14 days of expansion (Table 5).

Table 5

Quarry	Combination	% Exp. after 14 days	Classification
QA/1	Agg.+OPC	0.159	susceptible to reactive
	Agg.+PPC	0.035	innocuous
	Agg.+PSC	0.061	innocuous
QA/2	Agg.+OPC	0.170	susceptible to reactive
	Agg.+PPC	0.049	innocuous
	Agg.+PSC	0.063	innocuous
QA/3	Agg.+OPC	0.147	susceptible to reactive
	Agg.+PPC	0.025	innocuous
	Agg.+PSC	0.071	innocuous
QA/4	Agg.+OPC	0.149	susceptible to reactive
	Agg.+PPC	0.047	innocuous
	Agg.+PSC	0.070	innocuous
QA/5	Agg.+OPC	0.151	susceptible to reactive
	Agg.+PPC	0.056	innocuous
	Agg.+PSC	0.079	innocuous
QA/6	Agg.+OPC	0.129	susceptible to reactive
	Agg.+PPC	0.029	innocuous
	Agg.+PSC	0.067	innocuous

1. *Quarry QA/1*

The percentage expansion on 14-days suggests that aggregate is both innocuous and deleterious with OPC, while innocuous with PPC and PSC both. However, when compared to PSC at 14 days, the use of PPC limits the expansion owing to ASR more effectively (Figure4).

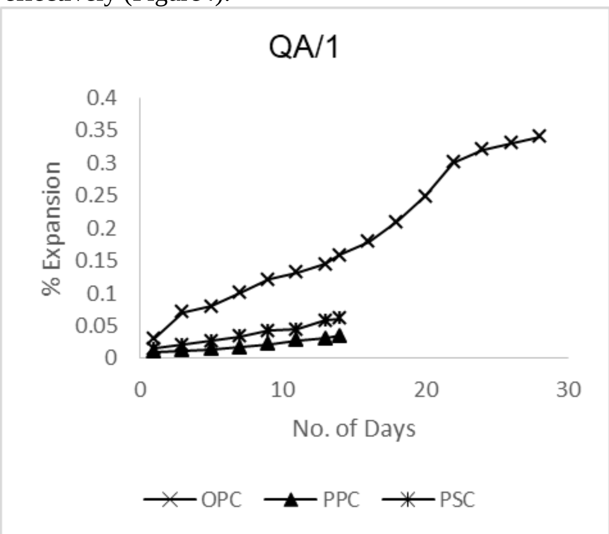

Figure: 4

2. *Quarry QA/2*

The percentage expansion on 14-days suggests that aggregate is both innocuous and deleterious with OPC, while innocuous with PPC and PSC both. However, when compared to PSC at 14 days, the use of PPC limits the expansion owing to ASR more effectively (Figure5).

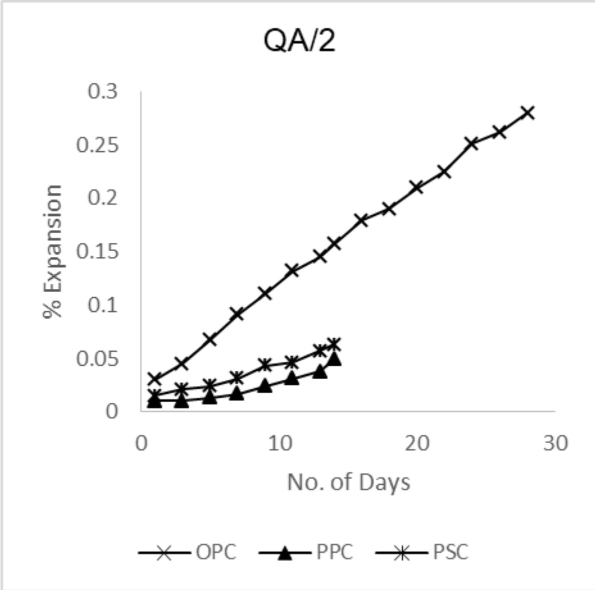

Figure: 5

3. *Quarry QA/3*

The percentage expansion on 14-days suggests that aggregate is both innocuous and deleterious with OPC, while innocuous with PPC and PSC both. However, when compared to PSC at 14 days, the use of PPC limits the expansion owing to ASR more effectively (Figure6).

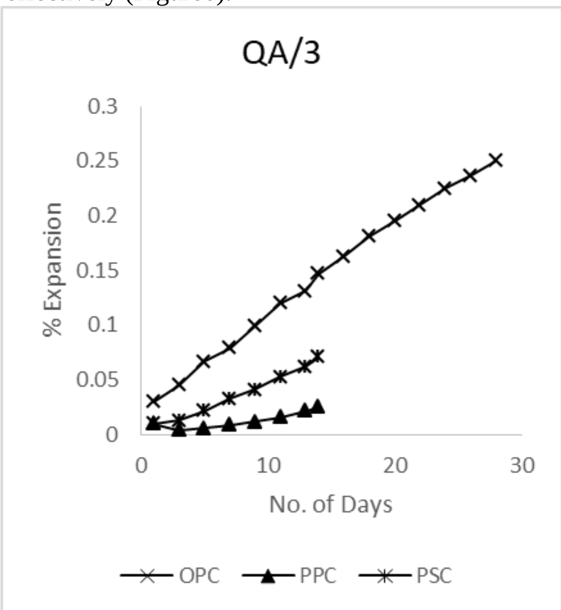

Figure: 6

4. *Quarry QA/4*

The percentage expansion on 14-days suggests that aggregate is both innocuous and deleterious with OPC, while innocuous with PPC and PSC both. However, when compared to PSC at 14 days, the use of PPC limits the expansion owing to ASR more effectively (Figure 7).

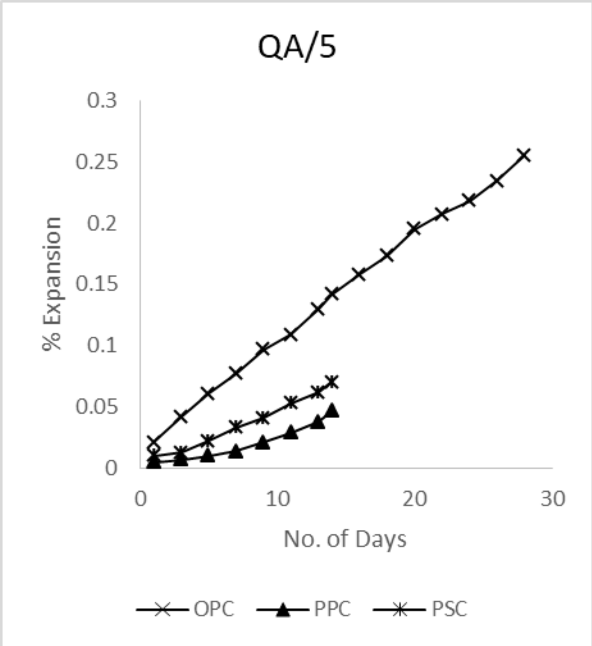

Figure: 7

5. *Quarry QA/5*

The percentage expansion on 14-days suggests that aggregate is both innocuous and deleterious with OPC, while innocuous with PPC and PSC both. However, when compared to PSC at 14 days, the use of PPC limits the expansion owing to ASR more effectively (Figure8)

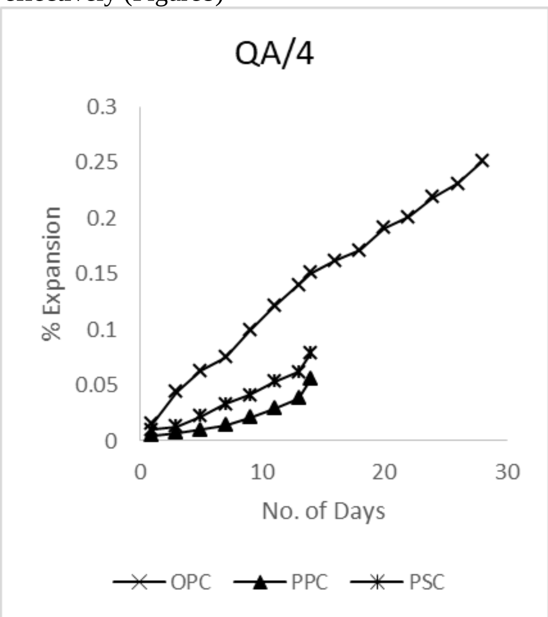

Figure: 8

6. *Quarry QA/6*

The percentage expansion on 14-days suggests that aggregate is both innocuous and deleterious with OPC, while innocuous with PPC and PSC both. However, when compared to PSC at 14 days, the use of PPC limits the expansion owing to ASR more effectively (Figure9).

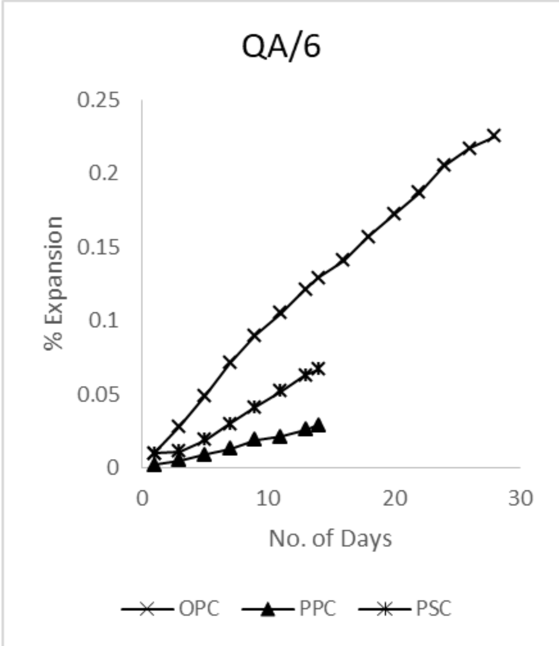

Figure: 9

V. CONCLUSION

The reactivity from these aggregates, as well as the effect of employing OPC, PPC, and PSC on their reactivity, were assessed experimentally using the accelerated mortar bar test method as per ASTM C 1260 and ASTM C1567, as well as petrographical analysis as per ASTM C 295. The combination of OPC with these aggregates has been proven to be reactive, while the test results clearly reveal that these aggregate shows innocuous nature when use with PPC or PSC instead of OPC. It is also found from the investigation that for the considered aggregate PPC arrest ASR expansion more effectively as compare to PSC.

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